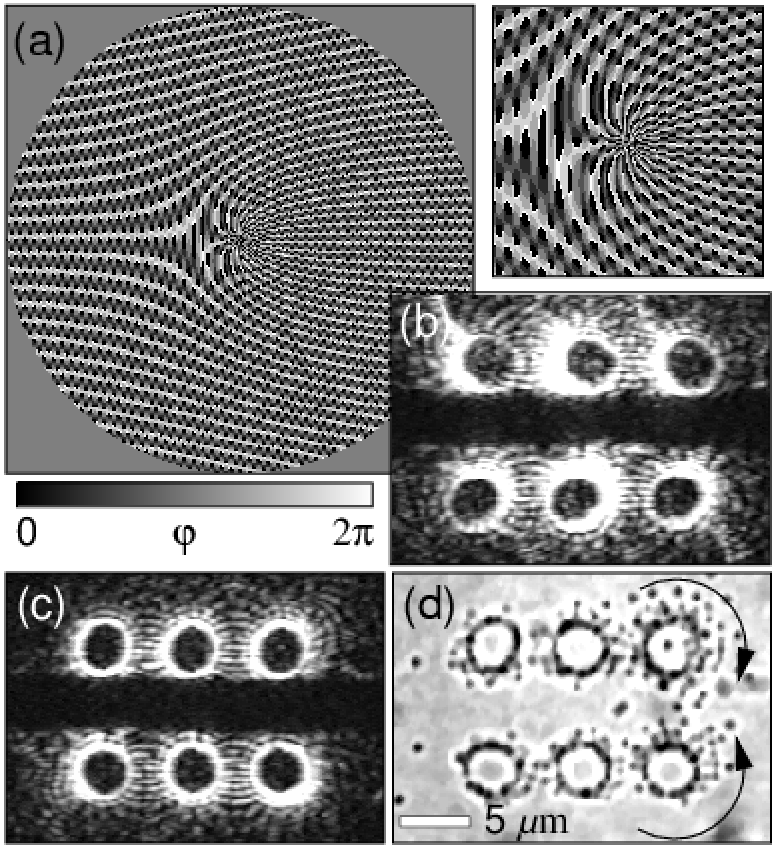
A Microoptomechanical Pump Created and Driven by a Computer-Designed Hologram

David G. Grier, New York University, DMR-0304906

The forces exerted by strongly focused beams of light can organize mesoscopic matter into interesting and useful structures. Sculpting the light with specially designed holograms enables us not only to trap small objects in arbitrary three-dimensional configurations, but also to exert torques on them, in this case creating and powering a microfluidic pump out of colloidal particles dispersed in fluid. With features as small as a few hundred nanometers, this all-optical pump requires no microfabrication and can be dynamically reconfigured.



Nature **424**, 810 (2003)
Optics Express **12**, 1144 (2004)

Computer-designed phase hologram (a) encodes an array of ring-like optical vortices (b). The optimized array (c) drives particles in counter-rotating circles, thereby pumping surrounding fluid (d).

•As biomedical and chemical technology shrinks to ever smaller scales, there is an increasingly pressing need for active pumps and mixers that operate on length scales ranging from the size of a few molecules up to the size of living microbes. Scaling down conventional pumps, valves and motors to operate in this arena has proved exceedingly difficult. This image shows an alternative approach that bypasses all of the technological hurdles posed by micro- and nanofabrication by leveraging a recent breakthrough in the theory and practice of computer-generated holography. A phase hologram, shown in (a), transforms a conventional laser beam into six specially crafted beams of light. Ordinarily such beams would focus to a discrete spot of light to form an optical trap known as an optical tweezer. However, the specially designed hologram endows each beam with a helical twist that causes them to focus into the rings of light shown in (c). These rings of light also act as traps, and can be seen collecting 700 nanometer diameter colloidal particles from an aqueous dispersion. The light's helical twist exerts a torque on the trapped objects, and they spin around the rings at up to several hundred RPM. As they spin, the particles create a steady, controlled flow of water down the channel between the rows of rings, which can be as small as a micrometer across. This holographic optical trapping pattern, therefore, acts as a microfluidic pump assembled and driven by a single static beam of light, with no microfabrication and no moving parts.

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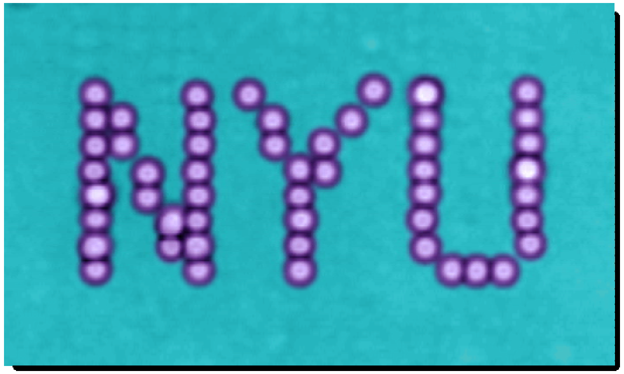
Education:
Three undergraduate REU students (Andrea Martin, Karen Kasza, and Meeri Kim) contributed to this program. Andrea is currently a graduate student at CalTech, Karen is a graduate student in Dave Weitz's group at Harvard, and Meeri is in her final year at Boston University. Two of the graduate students who pioneered holographic optical vortex arrays, Jennifer Curtis and Brian Koss are postdocs in biophysics at Heidelberg and the Naval Research Laboratory, respectively. Eric Dufresne is an assistant professor at Yale. Kosta Ladavac is a graduate student at NYU.

Societal Impact:
Holographic optical trapping, developed with DMR support, offers unprecedented control over the mesoscopic world. Applications range from surgery within living cells to manufacturing mesoscopic sensors, to rapidly sorting fluid-borne objects with unparalleled selectivity. This technology has been commercialized and is being rapidly adopted for a wide range of industrial applications.



Holographic optical trapping was developed with support from the NSF and has led to the birth of a new industry. Creating microfluidic pumps is just one example of the control that computer-generated holograms can exert over the microscopic domain, with other application areas including massively parallel continuously optimized cell sorting for biological and pharmaceutical research and development, three-dimensional assembly of hierarchically organized heterostructures of photonic devices and sensors, and nano-surgery within living biological cells.

This also is an outstanding platform for teaching students at all levels about the microscopic processes underlying everyday events such as melting and freezing, the lifecycle of cells and the emergent properties of materials, many of which play themselves out on the micrometer length scale accessible to manipulation and transformation with holographic optical traps.